Metalized MIC Substrates Using High K Dielectric Resonator Materials*

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Introduction

There are four basic circuit constructions for microwave communications systems that are either in use or under development: the mounting of discrete devices on PC boards, thick-film MICs, thin-film MICs and monolithic microwave integrated circuits (MMICs). Of these, PC board circuits have the advantage of low cost but the disadvantage of requiring the largest volume of the four types. Thick-film MICs using alumina substrates can miniaturize circuits, but they lack precise pattern control. Thus the thin-film MICs are used for industrial applications since they can satisfy the demands for high reliability, precise patterning and good producibility. Although MMICs are useful for miniaturization and have high reliability and low dissipation power, they have not been put into practical use because of their high cost.

We describe in this paper newly developed metalized substrates using high permittivity dielectric resonator materials. Their pore sizes were reduced to 2 μm average and 5 μm maximum so that they could be covered with high resolution circuit patterns. Compared with thin-film alumina substrates, they have the following advantages and disadvantages. The advantages are as follows:

- Since they have higher dielectric constants, circuits utilizing electric length elements (such as stubs or filters) are miniaturized.
- Since they have a temperature coefficient of 0 ppm/°C, temperature-stable microstrip line filters can be constructed directly on the substrate.

The disadvantages are as follows:

- Thermal conductivity of these materials is 10 times smaller than that of alumina.
- They have flexural strength 50 to 70 percent that of alumina.
- They are expensive since they need surface polishing.

Other characteristics (such as surface roughness, pore size and distribution, tensile strength between substrate and metalized electrode, and thickness of metalization) are

*Invited paper.

[illegible]

comparable to those of alumina substrates.

The technique used to join the metalized substrate to the metal case and reliability test results also are reported in this paper, together with an example of a filter application.

Properties of High K Materials

Two kinds of high K materials, K=38 and K=88, were used for substrates.[1] Their electrical and physical properties are shown in comparison with high purity Al_2O_3 ceramics in Table 1. The Q values of these dielectrics theoretically follow the following equation at microwav frequencies:[2]

$$Q_D \times f = \text{constant}$$

where Q_D=1/tanδ, tanδ is the die lectric loss and f is the frequency.

The Q_D shown in Table 1 is th experimental value measured b Hakki and Coleman's dielectric res onator method.[3] Density and flexu ral strength are the values meas ured by using substrates 50 x 5 x 0. mm in size.

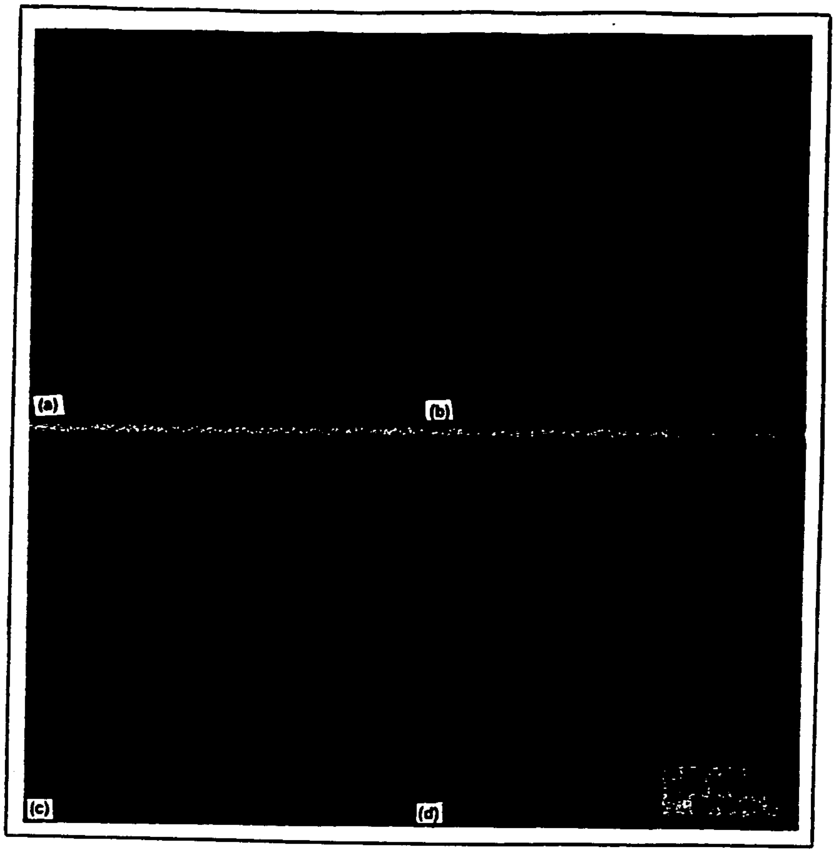

Fig. 1 Photographs of polished surfaces: (a) (Zr,Sn) TiO_4, K=38, powder pressing method and (b) sheeting method; (c) BaO-PbO-Nd_2O_3-TiO_2, K=88, powder pressing method; and (d) sheeting method.

Surface Finish of High K Substrates

In order to reduce pore size an the number of pores, the substrate were made by a sheeting metho using a doctor blade instead of powder pressing method.

Figure 1 shows photograph of the polished surfaces. Thes photographs were analyze using an image analysis systen (Pias Co.'s model LA-555). The por distribution in the surface area o 25,000 μm^2 for each sample was analyzed and the results are shown ir Table 2. For a K=38 substrate, bot the equivalent pore diameters an the number of pores were reduce greatly by the sheeting method. Fo the K=88 substrate, only the numbe of pores was reduced. Pore size wa not noticeably reduced, as it wa fairly small even by the pressin method. Being accompanied by th reduction of the number of pores the sheeting method improved th sintering density of the K=38 substrate from 5.14 to 5.25 g/cm^3 and

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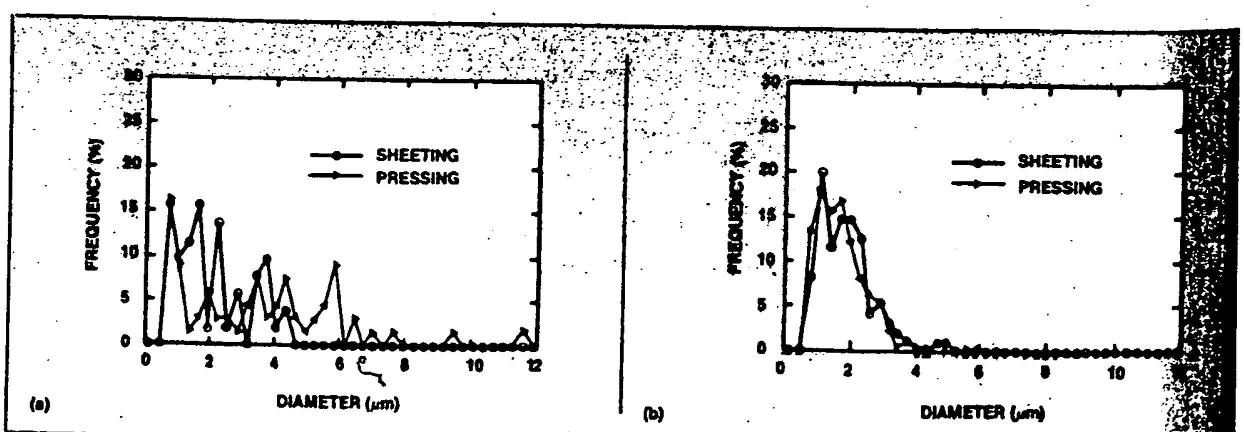

Fig. 2 Pore distributions of high K substrates: (a) (Zr,Sn) TiO_4 and (b) BaO-PbO-Nd_2O_3-TiO_2.

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of the K=88 substrate from 5.78 to 5.82 g/cm^3.

Figure 2 shows the pore distributions for these samples. It can be seen easily that the pores larger than 5 μm diminish by using the sheeting method on the K=38 substrate, and that the pore distribution remains the same for the K=88 substrate. The resultant pore diameters are about 2 μm (average) and 5 μm (max.) for both the K=38 and K=88 substrates. Since the surface roughness of these substrates is larger than 0.2 μm (R_a) or 2 μm (R_{max}) on the as-fired surface, they need to be polished for use in thin-film MICs. Their polished surface roughness is shown in Figure 3. The roughness of R_a=0.01 μm or R_{max}=0.09 μm is comparable to that of the as-fired smooth alumina substrates and is well-suited for thin-film metalized substrates.

Metalization

On the polished substrates, an underlayer of 300 Å of NiCr is deposited by the vacuum evaporation technique. The substrates then are plated with Au or Cu; the thickness of the electrodes is selected from 1 to 5 μm depending on the selected frequencies of operation.

Other characteristics of metalized substrates are shown in Table 3. The

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TABLE II
PORE DISTRIBUTION ON SURFACES OF HIGH K SUBSTRATES

Material	Parameter	Powder Pressing Method	Sheeting Method
$(Zr,Sn)TiO_4$ (K=38)	Average pore diameter (μm)	3.5	2.1
	Maximum pore diameter (μm)	11.6	4.4
	Pore area ratio (%)	4.7	0.8
	Number of pores (pcs/mm^2)	3500	1900
BaO-PbO-Nd_2O_3-TiO_2 (K=88)	Average pore diameter (μm)	1.7	1.6
	Maximum pore diameter (μm)	5.6	6.1
	Pore area ratio (%)	3.7	2.1
	Number of pores (pcs/mm^2)	13,800	8100

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tensile strength between substrate and electrode is 2 kg/mm^2 (average) and 1 kg/mm^2 (min.). The surface conductivities were measured by the dielectric rod resonator method described in reference 3. These conductivities have values of about 95 percent of the theoretical values of gold and copper. The tensile strength and surface conductivities are comparable to those of metalized alumina substrates.

The circuit patterns on the substrates are defined by photolithography. A mixture of iodine and potassium iodide solution may be used for etching.

Reliability

The life test of tensile strength and electric characteristics was performed on the substrates metalized with gold. The two test environmental conditions were temperatures of 85°C and 25 percent relative humidity, and 85°C and 85 percent relative humidity.

Figure 4 shows the results of the tensile strength life test. The data for 400 hours aging are now being obtained. We found that no significant deterioration of the tensile strength had occurred. Figure 5 shows the test samples for the data regarding aging of electric characteristics. The substrates were metalized with gold, and the half-wavelength microstrip line resonators with coupling capacitances were formed on them by using photolithographic techniques. The result is shown in Table 4. The resonant frequencies of the samples were 2 GHz. The deviations of resonant frequencies and unloaded Q values after 1,000 hours of environmental test were found to be less than the measuring error level, showing that high reliability can be achieved by these high K metalized substrates.

Application

Since the effective dielectric constants of these substrates are four to 10 times higher than those of alumina substrates, we can reduce the circuit size by a factor of two or three by using these substrates. Microwave circuits such as filters or os-

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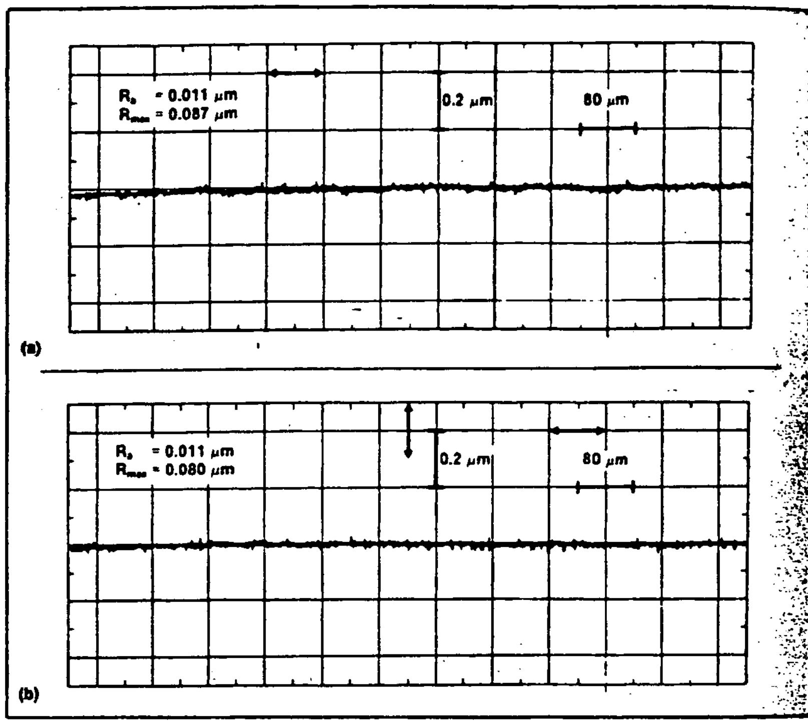

Fig. 3 Surface roughness of polished high K substrates: (a) (Zr,Sn) TiO_4, K=38; and (b) $BaO\text{-}PbO\text{-}Nd_2O_3\text{-}TiO_2$, K=88.

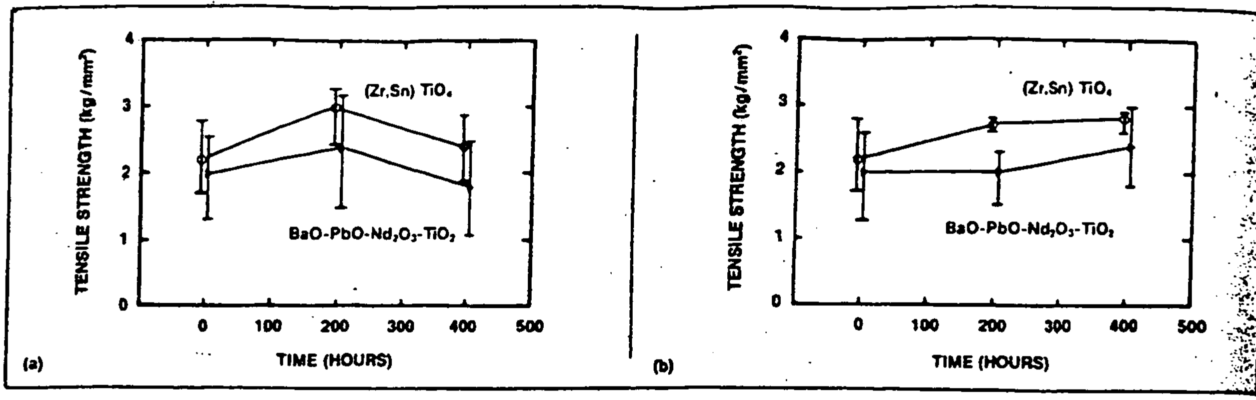

Fig. 4 Tensile strength after 400 hours of environmental test (n=5): (a) high temperature life test (85°C); and (b) humidity test (85°C, 85 percent relative humidity).

cillators can achieve good temperature stability since the temperature coefficient of these materials can be controlled to a level of 0 ppm/°C.

Figure 6 shows a photograph and characteristics of a 1 GHz-band bandpass filter for a direct broadcasting satellite (DBS) receiver. The interdigital filter consisting of seven microstrip line resonators was constructed by a photolithography technique. A material of K=88 was used for the substrate, and the chip size was reduced to 8 x 17 mm. The 12 GHz-band bandpass filter for a DBS converter, shown in Figure 8, was made in the same way. The parallel coupled filter consists of four microstrip line resonators.

Because the flexural strength of the high K substrate material is lower than that of the alumina substrate, high K substrates cannot withstand the thermal stress resulting from the difference of the thermal expansion coefficients between substrate and metal base, particularly when they are soldered to a metal base. One solution to this problem is to use a conductive adhesive such as Murata's CP-3P, which consists of fine silver particles suspended in epoxy resin and which has a low resistivity of 10^{-4} ohm-cm and tensile strength of 100 kg/cm^2.

Conclusion

We have developed metalized substrates using high K dielectric resonator materials. Their pore sizes were reduced to an average of 2 μm and a maximum of 5 μm. The substrates were polished to a surface roughness of 0.1 μm and were metalized with Au or Cu. Although these high K substrates have the

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TABLE III
METALIZATION CHARACTERISTICS

Surface roughness: R_a = 0.01 μm, R_{max} = 0.09 μm
Underlayer: NiCr thickness = 300 Å
Overlayer: Au or Cu thickness = 1 to 5 μm
Tensile strength: >1 kg/mm^2 (2 kg/mm^2 average)
Conductivity: 4.2 ohm^{-1}m^{-1} for Au; 5.5 ohm^{-1}m^{-1} for Cu

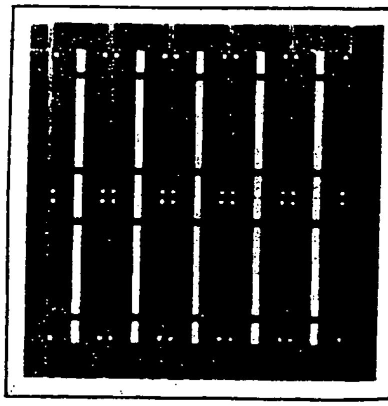

Fig. 5 Microstrip line resonators used for the life test of electric characteristics.

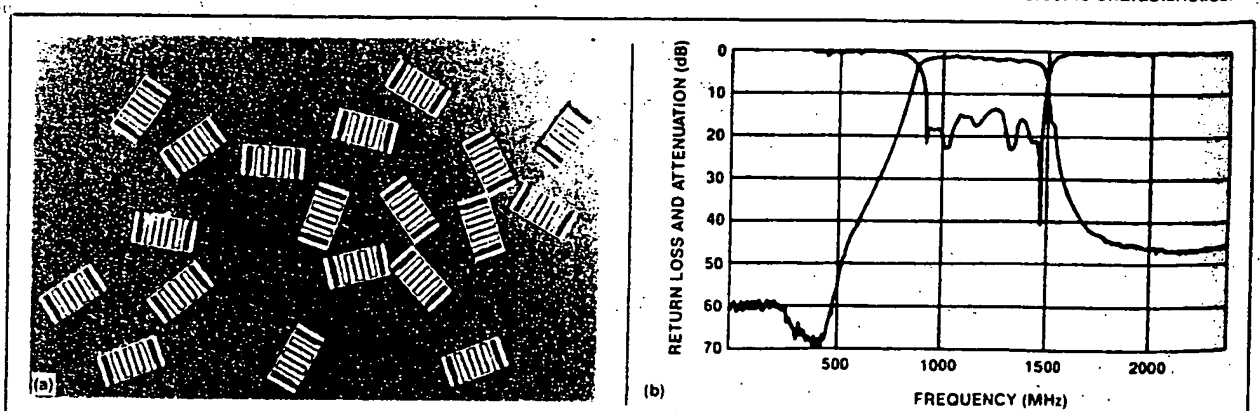

Fig. 6 (a) Photograph and (b) characteristics of a 1 GHz microstrip line filter.

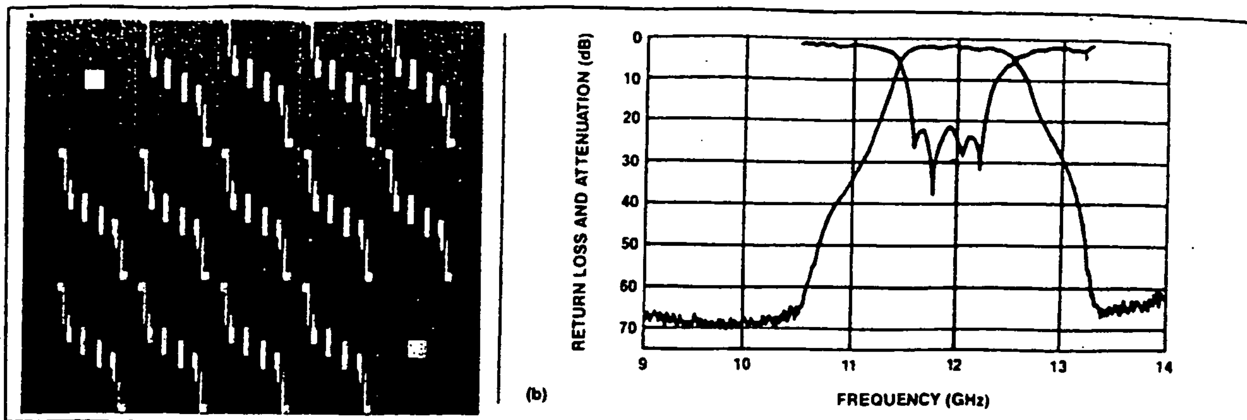

Fig. 7 (a) Photograph and (b) characteristics of a 12 GHz microstrip line filter.

TABLE IV
DEVIATIONS AFTER 1000 HOURS OF ENVIRONMENTAL TEST

Material	Type of Deviation	Deviation (%) at 85°C, 20% RH	Deviation (%) at 85°C, 85% RH
(Zr,Sn) TiO_4	$\Delta f/f_0$ $\Delta Q/Q_0$	<0.01 <0.5	<0.01 <0.5
BaO-PbO-Nd_2O_3-TiO_2	$\Delta f/f_0$ $\Delta Q/Q_0$	<0.01 <1.0	<0.01 <1.0
Initial Values: (Zr,Sn) TiO_4: f_0=2321 MHz, Q_0=123 BaO-PbO-Nd_2O_3-TiO_2: f_0=1654 MHz, Q_0=79			

disadvantage of lower flexural strength compared with alumina substrates, this disadvantage can be overcome by carefully choosing adhesives and mounting techniques. The high K substrate application is beginning to spread in the MIC field.

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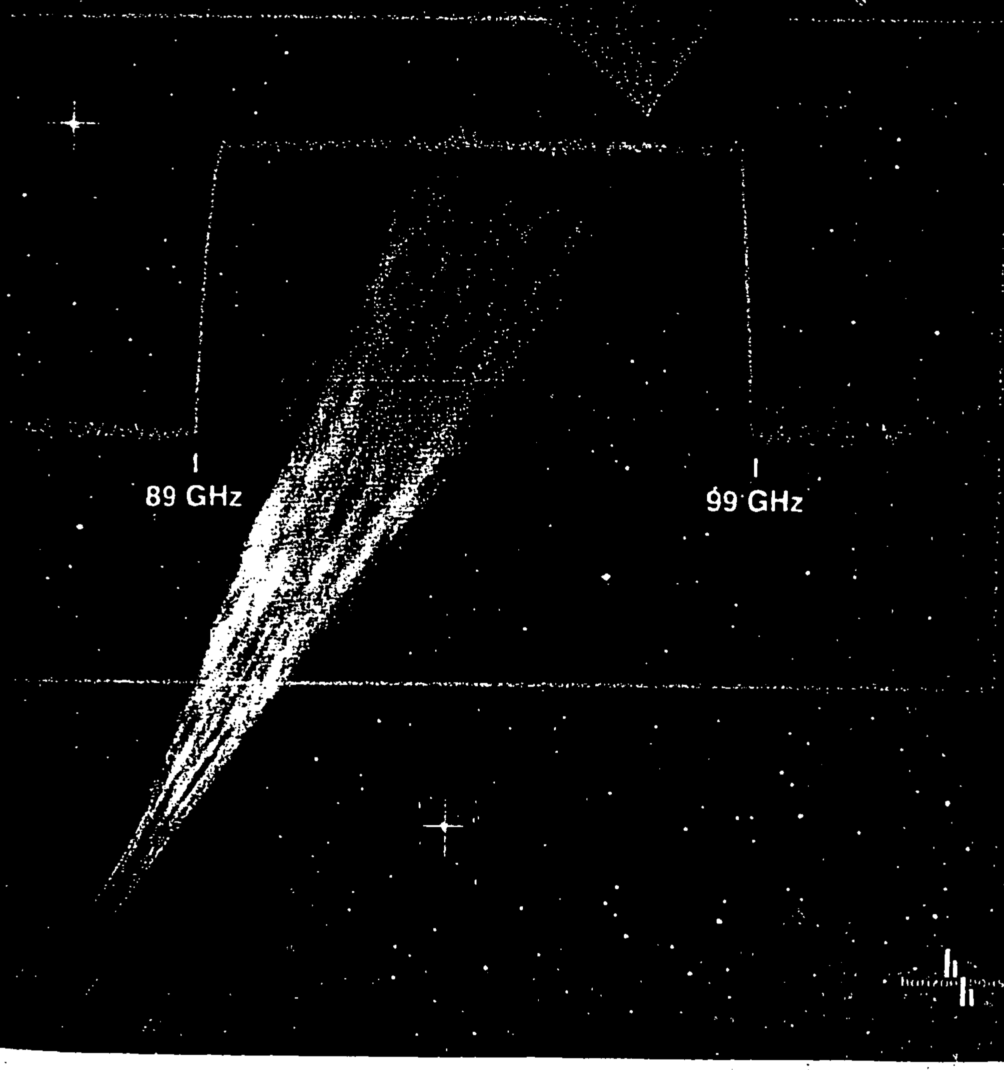

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